AD-A286 900

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NUWC-NPT Technical Document 10,564
29 March 1996

Multipurpose Processor (MPP) Accelerated Reliability Test Plan

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96-01840

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PREFACE

The Multipurpose Processor (MPP) Accelerated Reliability Test (ART) plan was prepared by the Electronics and Quality Assurance Division of the Engineering and Technical Services Department for use in the development and integration of commercial off-the-shelf equipment and systems. This plan analyzes accelerated reliability testing techniques, discusses the benefits of conducting such testing on the MPP, presents a detailed scheme for MPP testing, and outlines the follow-on analysis and reporting efforts to be performed. This ART plan is also intended as a template for other reliability testing.

This document was funded under NUWC Division Newport NSSN FY 95 Tasking, "Hardware Evaluation," principal investigator M. K. Nehra (Code 433). The sponsoring activity is the Program Executive Office for Submarines, J. Smerchansky (PMO-40141).

The Engineering and Technical Services Department gratefully acknowledges the efforts of all Naval Undersea Warfare Center and support personnel who contributed to this plan through its many reviews.

Reviewed and Approved: 29 March 1996

R. L. Brown
Head, Engineering and Technical Services Department

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	29 March 1996	

4. TITLE AND SUBTITLE

Multipurpose Processor (MPP) Accelerated Reliability Test Plan

5. FUNDING NUMBERS

6. AUTHOR(S)

Mandeep K. Nehra

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Naval Undersea Warfare Center Division
1176 Howell Street
Newport, RI 02841-1708

8. PERFORMING ORGANIZATION REPORT NUMBER

TD 10, 564

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Naval Sea Systems Command (PMO 4014?)
2531 Jefferson Davis Hwy
Arlington, VA 22242-5160

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

The Multipurpose Processor (MPP) is a new development system designed to provide array receiver and beamforming processing. The MPP, based on commercial off-the-shelf technologies, is critical to follow-on AN/BSY-1 system performance improvements. Current specifications require implementation of an extended reliability prediction, reliability development test (RDT), and failure analysis and corrective action system to assess hardware performance during system development. Traditional RDT methodology focuses on reliability growth at the lowest possible component level, implements sequential and separate tests for different environments, requires a minimum expected test time of three to five times the mean time between failure, and does not provide timely feedback to the design community. Furthermore, parts of the RDT process are not clearly applicable in a system development where COTS equipment is utilized. The accelerated reliability test (ART) plan presented here would provide accurate reliability data in shorter timeframes at reduced cost. ART methodology uses design of experiments to rationalize test performance; reduces the individual trial times, thereby reducing associated costs; implements combined stress testing; and implements stress range from operational to maximum design. This document details the development and application of ART methodology and presents a detailed plan for MPP testing.

14. SUBJECT TERMS

Reliability Testing   Commercial Off-the-Shelf Technologies
New Attack Submarine   AN/BSY-1 Combat System

15. NUMBER OF PAGES

50

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	SAR

EXECUTIVE SUMMARY

INTRODUCTION

The Multipurpose Processor (MPP) is a new development system designed to provide array receiver and beamforming processing. The MPP is based on commercial off-the-shelf (COTS) technology components, ruggedized at the cabinet boundary to meet specification requirements. The unit is critical to follow-on AN/BSY-1 system performance improvements, and its technology demonstrates most likely new attack submarine (NSSN) applications. Overall reliability experience with the components of this unit is minimal, especially in the Navy environment.

Current specifications *require* implementation of an extended reliability prediction, reliability development test (RDT), and a failure analysis and corrective action system (FRACAS) program to assess hardware performance during system development. The program is intended to identify and correct reliability deficiencies that occur over a period of several years and under benign laboratory conditions, i.e., a reliability program along the same lines of most historical system developments. This accelerated reliability test (ART) proposal demonstrates the deficiencies of the traditional approach and the benefits of ART in the new business environment.

BACKGROUND

Published/predicted reliability estimates for COTS and other equipment are uncertain relative to actual field performance. The essential reason for performing reliability development testing is, therefore, to validate these estimates. Traditional test/growth methodology as required in the NSSN specifications has the following disadvantages:

- focuses on reliability growth at lowest possible level,
- implements sequential and separate tests for different environments,
- requires an expected test time of three to five times the mean time between failure (MTBF) *without* failure,
- does not provide timely data feedback to the design community.

The actual purpose of reliability testing—to characterize equipment reliability in the field environment and identify critical reliability items—is often defeated.

Furthermore, the test, analyze, and fix (TAAF) and FRACAS programs that are part of the NSSN-specified RDT process are not clearly applicable in a system development where COTS equipment is utilized. By definition, COTS equipment cannot and will not be redesigned, no matter what reliability deficiencies are identified. Vendors are not likely to effect equipment changes for a small customer or nonstandard environment market, and in-house changes to the equipment would void COTS definitions.

The reliability of basic COTS hardware, including that of the MPP, is therefore fixed when bought; its quantification is equally uncertain. Measurement of this parameter early in the development process is even more important now, however, in order to effect changes in system architecture to achieve required system reliability.

ACCELERATED RELIABILITY TESTING

There is growing emphasis on innovative ART by the commercial and military communities. ART is beneficial because it

- uses existing stress test procedures in an analytically intelligent approach and methodology;
- returns a stress-dependent MTBF model, i.e., data returned relate directly to the environment of interest and are not simply a reliability "number"; and
- saves money, time, and other resources over traditional techniques because of designed efficiency.

By providing timely reliability data feedback, ART supports concurrent engineering and allows focus on reliability development at the system level where system architecture arrangements can be addressed. Timely data also supplant TAAF/FRACAS activity, results of which would be of limited utility given the Navy s mii 'mal influence on the original equipment manufacturers (OEMs) and process quality.

Given the benefits of ART over the specified RDT (TAAF/FRACAS) process, the Navy is strongly urged to exercise this proposed plan. Application of the methodology described will validate both MPP reliability performance and the use of ART for assessing additional COTS use in NSSN development.

METHODOLOGY

ART methodology: (1) uses design of experiments (DOE) to rationalize test performance; (2) reduces the number of trials required, test times at low stresses, and associated costs; (3) implements combined stress testing; and (4) implements stress range from operational to maximum design.

This plan proposes the following test parameters.

Test subjects/quantities:	1 MPP unit, with 3 allocable processor (AP) drawers (Reuse and repair of assemblies is expected to minimize the number of test assemblies.)
Stress factors and levels:	Temperature: 10°C, 40°C, and 70°C Power: 95 V, 105 V, and 115 V Vibration: 4 Hz, 18 Hz, and 32 Hz
Number of test trials:	9 per test assembly type, with 3 assemblies per test trial 3 stresses x 3 levels = 27 possible test trial combinations.
Test duration:	MPP testing: 250 hours AP testing: 1000 hours

RESOURCES REQUIRED

Table ES-1 provides a summary of resources required to conduct the proposed ART. Additional information on resources required by the traditional RDT (TAAF/FRACAS) process is also presented for comparison.

Table ES-1. Total Resources Required Comparison Matrix

Resource	ART	RDT (TAAF/FRACAS)
Test Duration:		(Note 1)
• MPP	250 hours	1050 hours
• AP	1000 hours	4500 hours
• SC	(Note 2)	6800 hours
• TAD	(Note 2)	13600 hours
• Facilities	1000-1250 hours	4500 hours
Test Units/Spares		
• Total MPPs	1 unit, 3 AP drawers	2+ units
• Spare LRUs	20 modules	Multiple (Note 3)
Test Personnel		
• Equipment	120 work-hours	450 work-hours
• Facility	1250 work-hours	4500 work-hours
• Reliability Test	120 work-hours	2250 work-hours
• Failure Analysis	120 work-hours	450 work-hours
Total	1600 work-hours	7600 work-hours

NOTES:

1. Best-case estimates were taken for traditional RDT comparisons.
2. Reliability data from AP and MPP testing will be evaluated based on the relative complexity of the signal conditioning (SC) drawer and the towed array drawer (TAD).
3. Lowest replaceable units (LRUs) will be replaced on an as-fail basis, and failed modules will be sent to a repair facility.

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LIST OF ABBREVIATIONS AND ACRONYMS

ANOVA	Analysis of variance
AP	Allocable processor
ART	Accelerated reliability test
AUT	Assembly under test
BOT	Baseline operating test
COTS	Commercial off the shelf
DC	Direct current
DOE	Design of experiments
FDDI	Fiber distributed data interface
FRACAS	Failure analysis and corrective action system
GBE	Ground benign environment
HA	Hull array
IPL	Initial program load
LRU	Lowest replaceable unit
MPP	Multipurpose processor
MTBF	Mean time between failure
NS	Naval sheltered
NSSN	New attack submarine
NTDS	Naval tactical data system
NUWC	Naval Undersea Warfare Center
OBE	Outbound electronics
OEM	Original equipment manufacturer
PDF	Probability density function
PM	Performance monitoring
RDT	Reliability development test
SC	Signal conditioning
TA	Towed array
TAAF	Test, analyze, and fix
TAD	Towed array drawer
VME	Versa module eurocard

MULTIPURPOSE PROCESSOR (MPP)
ACCELERATED RELIABILITY TEST PLAN

1. INTRODUCTION

1.1 PURPOSE

This Multipurpose Processor (MPP) Accelerated Reliability Test (ART) plan is submitted by the Engineering and Technical Services Department of the Naval Undersea Warfare Center (NUWC) Division, Newport, Rhode Island, to support concurrent engineering solutions for the AN/BSY-1(V) and New Attack Submarine (NSSN) commercial off-the-shelf (COTS) programs.

The primary purpose of COTS equipment reliability testing is to characterize the reliability/availability performance of hardware prior to final system design and provide feedback to the design community.

1.2 SCOPE

This ART plan discusses the following areas in detail:

- test methodology
- test conduct
- test resources.

1.3 BACKGROUND

Reliability testing, tracking, and assessments are essential parts of a system life cycle. The robustness of a system reliability program is directly linked to its operation, maintainability, and availability. Traditional military material reliability testing techniques call for subjecting the assembly under test (AUT) (i.e., system, unit, or assembly) to extreme environmental stresses while monitoring for signs of failure over time. Extreme environmental stresses are defined as outside the AUT predefined design range. MIL-HDBK-781[1] guidelines require lengthy minimum test times. Standard test plans call for 2.7 to 4.4 times the mean time between failure (MTBF) with failure-free operation, resulting in expected test times of 3.4 to 11.4 times the MTBF with expected failures. A more detailed evaluation of MIL-HDBK-781 MTBF assurance tests, sequential tests, and fixed-time tests is necessary to definitively measure decision risks, but the proposed ART plan methodology shows a worst-case test time of only 3.6 times the AUT MTBF. The expected test time for the ART methodology is evaluated to be less than 0.8 times the AUT estimated MTBF.

This document proposes reliability testing of the MPP because of its COTS composition and its criticality to the submarine mission. Reliability testing of the MPP using the traditional testing techniques with a minimally acceptable estimated MTBF of 250 hours would require from 675 to 1100 unit hours (0.9 to 1.5 months) of test time. Also, for testing of the allocable processor (AP) drawer with a minimally acceptable estimated MTBF of 1200 hours, test times would range from 3240 to 5280 unit-hours (4.5 to 7.3 months). Performing tests of such duration would be costly and would not allow reliability performance feedback during the preproduction of the MPP equipment. A means of accelerating the test times and reducing the relative expense must be devised to produce information that is sufficiently timely to affect the reliability design of the MPP unit. The following discussion presents an accelerated test procedure that reduces test times without affecting the integrity of the data collected.

The accelerated reliability testing techniques developed by Barry T. McKinney at Rome Laboratory[2] provide reliability data in a timely fashion and minimize the expense of data collection. These testing techniques are designed to reduce the time and expense incurred by the standard reliability testing while still providing high-confidence results. This testing is formulated using the design of experiments (DOE) methodology, which in its most basic form is a rational scientific planning of test conduct that yields experimentation goals.[3]

The following steps are necessary to conduct an accelerated test under the DOE:

1. Identify the reliability parameter(s) to be studied.

2. Identify those stresses that have the greatest impact on system performance and the selected reliability parameter(s).

3. Identify the levels of stress to be induced on the AUT.

4. Develop a matrix that associates the combination of stresses to be tested along with their stress levels.

5. Evaluate the maximum time per test trial for a given level of stress combination severity and quantity of AUTs.

6. Randomly test with combined stresses and collect failure information.

7. Perform analysis of variance (ANOVA) on recorded data.

1.4 BENEFITS

1.4.1 Unit- and Assembly-Level Testing

This MPP ART plan proposes reliability testing at the unit and the assembly, or drawer, level. Testing at both the unit and assembly levels allows calculation of the reliability of the remaining assemblies, given that the resulting data define the reliability of all assemblies along with the unit level. Assembly-level reliability data generated by this test will substantiate new development system-level reliability estimates, given that the functional complexity of the individual drawers of the MPP is representative of the expected characteristics of new development equipment. New development systems are expected to consist of quantities of assemblies integrated in structurally reinforced enclosures.

Reliability data based on unit/assembly accelerated testing provide a basis for identifying design, selection/application, and environmental problem areas and provide essential inputs to system-level predictions.

1.4.2 Test Impact

1.4.2.1 Resources Required. The conduct of ART requires fewer resources than traditional RDT test, analyze, and fix (TAAF) and failure analysis and corrective action system (FRACAS) techniques. Section 4.6 provides a general summary of the projected resource requirements for the two methodologies for equivalent test objectives. Even at this gross level, the comparison demonstrates a substantial reduction in personnel and equipment resource allocation. ART conducted under DOE methodology reduces the cost of testing by better weighing the relationship between testing time and quantity of required AUTs. Reducing test time allocates personnel and test facility expenditures efficiently, making resources available to other programs and agencies. In addition, reducing the number of test assemblies reduces purchase expenditures.

1.4.2.2 Quality of Data. ART provides a high level of confidence in the data generated. Traditional reliability test activities provided a measure of reliability based on benign test environments and operational conditions. Duplicating realistic operating conditions (e.g., vibration levels, temperatures) in the lab was normally too difficult and cost-prohibitive. Equipment can operate longer before failure under these benign test conditions. The ART methodology postulated in this document provides assembly-level reliability assessment based on a realistic design and operational environment conditions. The resultant data are therefore more meaningful and predictive.

The ART methodology returns an environment-dependent reliability (MTBF) model as a result of the design of the test and its outputs. This model allows realistic assessment of the reliability of the subject throughout its design and within the operational environment boundaries. Traditional test activities and methodologies do not provide this level of information, they provide only a projection of reliability development over time.

By applying ART, test engineers and system developers achieve a better understanding of their systems and the effects that various stresses have on the individual assemblies. Armed with a better understanding of how individual subassemblies are affected by environmental stresses, engineers can develop a more accurate system-level reliability model that can help reduce the cost of the design of COTS systems.

1.4.2.3 Reliability Development Test (TAAF/FRACAS) Relevance. Traditional *assembly*-level testing and corrective action techniques are not clearly applicable in a system design environment where COTS equipment is being used. The reliability/quality of COTS equipment cannot be affected by a failure mechanism assessment; i.e., COTS equipment will not be redesigned. Its reliability is a fixed and relatively unknown quantity. ART provides a rapid, inexpensive assessment of assembly-level reliability to support *system*-level reliability development, i.e., it supports TAAF/FRACAS at a system level. Application of TAAF at lower levels of COTS equipment is not applicable because of the fixed reliability and design of COTS equipment and the Navy's minimum influence on OEMs. Timely ART results therefore supplant FRACAS requirements and traditional reliability testing.

1.4.3 Design Impact

System reliability assessments combine lower level reliability data to indicate equipment reliability at successively higher levels from subassemblies to the system. A shortfall in basic reliability may be offset by amending the design architecture, by use of higher quality parts, or by trading off detailed performance tolerances. However, the use of COTS components precludes design architecture changes, therefore, any shortfall in mission reliability must be offset by the use of redundancy in system architecture or by changes in functionality and reliability. ART provides information on lower level assemblies at an early point in system development when appropriate change action is most tolerable from a programmatic, basic reliability, and mission reliability viewpoint. ART therefore supports a concurrent engineering environment by providing equipment design, test, and reliability engineers with reliability data before the production stage. This advanced supply of data allows the engineers to review fault data and, if necessary, redesign a more robust system architecture.

1.5 FOCUS

1.5.1 Accelerated Reliability Test Plan

The main focus of the MPP ART plan is to detail the elements associated with the formulation of the test, including its feasibility, benefits, and necessary resources such as time, test assemblies, facilities, personnel, and test equipment. Additionally, test configuration concepts and options that maximize using current government assets can be employed to offset the capital costs of purchasing specific hardware for the testing.

1.5.2 Assemblies Under Test

The failure rate of the MPP unit consists of the sum of the failure rates of its subsystems: the three allocable processor (AP) drawers; the towed array drawer (TAD), the signal conditioning (SC) drawer, and the remaining miscellaneous MPP hardware (e.g., fans, connectors, and wiring harnesses). The MPP specification lists system- and subsystem-level MTBF requirements. It is proposed that the MPP unit and the AP drawers be reliability-tested to obtain their failure rates. These units/assemblies have been chosen to obtain the most reliability data in the shortest test time. The SC drawer failure rate may be extrapolated from the AP drawer failure rate because of the similarity in their electronic card complement. Due to the known failure rate characteristics of the miscellaneous subsystem, its reliability can be easily be estimated. Therefore, an MTBF for the TAD may be calculated with a high degree of confidence by performing reliability testing on the MPP and the AP drawers, extrapolating the SC drawer reliability, and estimating the miscellaneous subsystem reliability.

2. TEST METHODOLOGY

2.1 DESIGN OF EXPERIMENTS

This ART plan follows documented work on the design of experiments and proven documented accelerated reliability methodologies. References used in designing the MPP ART plan immediately follow section 4 of this document.

Using DOE,[4] ART combines test stresses during planned experiments to accelerate the overall testing. The testing is unique for the following reasons.

1. The method employs the efficiency of designed experimentation as a contributing "accelerator" of the test. One of the main reasons for using designed experimentation is the need to combine stresses during individual test trials to reduce the amount of test time required to test all stresses. In addition, by reducing the amount of testing done at the lowest stress levels, where failures are unlikely to occur, only a subset of the total possible combinations will be tested, further accelerating the test.

2. The test trials are randomized to eliminate any errors due to time dependency. Thus, by time averaging all of the AUTs, the sequence of the tests can be randomized, eliminating errors associated with the accumulated test times and associated time wear. Furthermore, all testing will take place within the operational service life of the MPP. The MPP designed service life is 10 years (87,600 hours) and in the worst case (1 unit seeing all test trials for the maximum time allowed per trial) the AP drawer will see a maximum of only 4338 test hours. Because the time required for testing is less than 5.5 percent of the AP drawer service life, the effects of time wear on the unit are assumed to be negligible. In addition, randomization supports the assumption regarding the independence of various errors, particularly measurement errors discussed in section 2.2

3. The stress range of the test overlaps the operational environment of the test unit and is not above maximum design levels. The test must be designed so that the parameters of the test range only from operational to maximum design specifications. Inducing stresses that exceed maximum design specification will cause unrealistic faults that corrupt the data and have no bearing on the test assembly reliability. Testing within these parameters eliminates the need for extrapolation of results, increasing the confidence level of the data gathered and simplifying analysis. Figure 1 displays the stress range selection criteria.

4. The method has been specifically developed to test and model all levels of assembly. The experiment must be planned so that all functions of the assembly are tested.

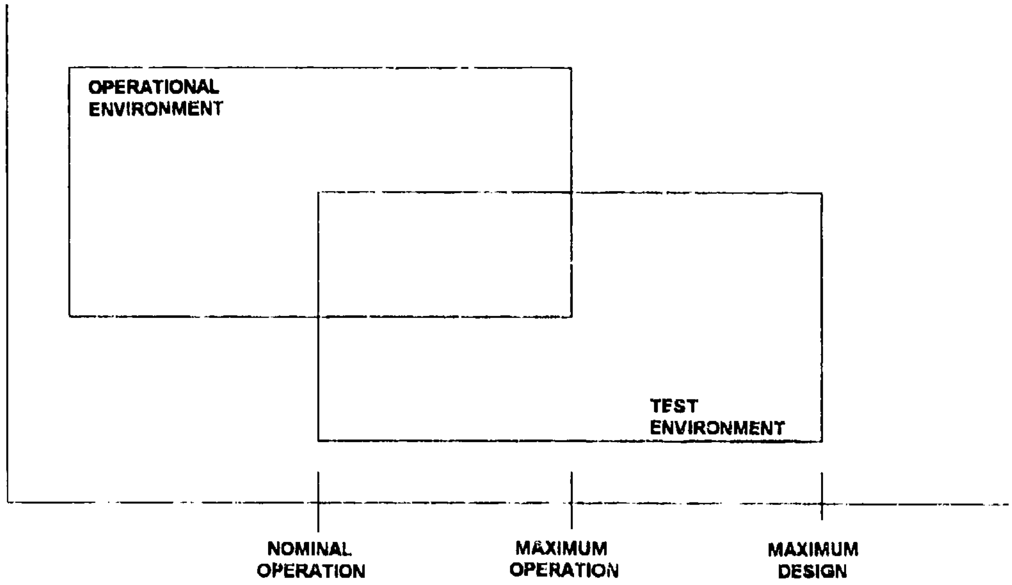

Figure 1. Stress Range Selection Criteria

5. The method requires no extrapolation. Because testing is performed within the operational parameters of the test device, the results of the test are a functional mapping of the stress relationship for the operational parameters. All data outside maximum design specifications are ignored because of the abnormal failure that occurs and because these failures are never seen during normal usage.

6. The method uses a combined stress environment for the specific purpose of modeling all effects. Previous testing explored only one stress at a time. The assumption of modeling stresses by using of orthogonal polynomials allows acceleration due to multistress testing application.

7. There are no assumptions concerning the specific shape of the life distribution functions.

2.2 METHODOLOGY PRINCIPLES

The following paragraphs develop and demonstrate a reliability test methodology specifically designed for higher order assemblies.[2] The most important contributions of this method are its ability to quantitatively partition the individual stress effects and its ability to predict the unit reliability and performance without extrapolating beyond the limits of the accelerated test data.

The proposed methodology, realized by using DOE, is intended for use in resolving the following experimental expression:

$$Y_{ij} = \mu + A_i + B_j + \ldots + \varepsilon_{ij}, \tag{1}$$

where

Y_{ij} = dependent variable/parameter,
μ = expected response,
A_i = effect on Y_{ij} from factor A,
B_j = effect on Y_{ij} from factor B,
ε_{ij} = error,
$i, j, \ldots$ = levels of factors A, B.

The testing and analysis of data outlined in the following pages will resolve values for the effect parameters (i.e., $A_i, B_j, \varepsilon_{ij}$) and allow application of the model expression to any level (i.e., i, j, k) of factors within the limits of the test environment. An experiment was conducted to provide data on effects and the various levels of stress factors noted. The effects (A_i, B_j, etc.) were tested in a classical sense using statistical methods, including a null hypothesis according to a standard ANOVA. The factors found to have significant effects on the experiment were then represented in the model expression, which then allowed prediction of the dependent variable, in this case MTBF, based on the stress values.

The assumptions necessary for this testing and modeling methodology do not deviate appreciably from the assumptions of common reliability testing techniques. However, by not requiring specific assumptions of a time-to-failure distribution and a stress/performance relationship function, the assumptions required for this methodology are considerably less restrictive. The following bulleted items are the assumptions required for AKT methodology.

- The factors being studied are quantitative and can be described as points on a scale.
- The errors are independent and normally distributed with a zero mean and common variance.
- The design limits of the test article can be determined (or approximated).
- Multiple, identical units are available for testing.
- The test stresses can be applied simultaneously.
- The factors can be equally spaced from one level to the next.

For purposes of this test, interactions among the stresses are considered negligible. All three elements (temperature, vibration, and power) are assumed to operate independently. Because of the hundreds of possible factors working against a fielded military system, maintenance-induced failures, and false alarms (retested without failure), it is not considered cost-effective to invest the time, expense, and additional data collection efforts required to quantify the two- and three-way interactions among stresses. The level of significance for the error associated with omission of these stress reactions will be explored during the ANOVA analysis of the resultant data. The ANOVA analysis will validate the acceptability of this assumption.

The experimental process can be broken down into three phases: planning, design, and analysis. The planning phase includes determining the performance parameter(s) of interest, the types and levels of stress used in the test, and the analysis technique used to study the test data. The design phase determines the type of experimental design most suitable and efficient for the specific purposes of studying reliability, establishes the amount of test time and number of test units that will be required, and includes a simple tradeoff analysis between test time and the number of test units. The analysis phase of the method identifies and quantifies the demonstrated effects of stress.

2.3 TEST PARAMETERS

2.3.1 Assemblies Under Test

The MPP serves as a towed array (TA) and hull array (HA) multi-array receiver that can perform the necessary signal conditioning of the received signals, format the data into digital format, and perform beamformation and signal processing techniques on the digital data to create the desired output data for display processing. The MPP can be ruggedized at the cabinet boundary to meet the requirements defined in the MPP system specification and to allow maximum use of convection-cooled commercial grade products within the cabinet. The MPP provides passive detection of contacts through various acoustic sensors, as well as the capability to track contacts automatically and manually. In addition, the MPP provides support to a host computer by processing and distributing acoustic and environmental data obtained from various underwater sensors.

The MPP consists of one TAD, one SC drawer, and three AP drawers. The TAD and the SC drawer contain all the external array interfaces as well as the standard and miscellaneous interfaces to allow the MPP to be integrated with a host computer system. The TAD and the SC drawer receive and format data and distribute the data to any or all of the AP drawers for beamformation and signal processing. All AP drawers have identical hardware configurations and support processing of any of the array input under software control. The AP drawers contain an open standard interface to allow the final signal-processed data to be transferred to a host computer for display at a man/machine interface.

The MPP provides facilities for the following interfaces:

- host computer interface (NTDS-32),
- host audio interface (NTDS-16),
- fiber distributed data interface (FDDI),
- TB-16 towed array (TA) outbound electronics (OBE) element interface,
- TB-23 or TB-29 TA OBE element interface,

- hull array (HA) data digital element interface,
- analog test target waveform input interface,
- TA/HA analog record interface,
- TB-29 element record/playback interface,
- TB-16/23 element record/playback interface, and
- digital multibeam output interface.

2.3.2 Determination of Test Stress and Levels

The environmental requirements for the MPP are listed in the *System Segment Specifications for the Multi-Purpose Processor.*[5] The following environmental stress conditions were selected as stresses that have the greatest effect on system performance and the greatest adverse effect on reliability:

- temperature,
- vibration, and
- power (voltage).

Each test stress will be induced at three test levels.

- level 1 (low stress) - nominal operational levels,
- level 2 (medium stress) - maximum operational levels, and
- level 3 (high stress) - maximum specification levels.

As stated previously, the level of significance of the error associated with the exclusion of stress interactions will be explored during the ANOVA analysis of the resultant data. That analysis will determine the acceptability of the assumption to neglect the contribution from these environmental stresses.

The following environmental stresses were also examined for possible incorporation into the ART MPP/AP plan and were excluded on the basis of their contribution to the test results

1. Humidity - Humidity and the induction of dendrite growth due to the ionic contaminates left on the surface of the circuit board are believed to be a key failure mechanism of commercial electronic equipment operating in noncontrolled environments. This factor, however, is a characteristic of the manufacturing process and should be tested during the MPP environmental qualifications. Also, data from MIL-STD-810[6] indicate that controlled relative humidity has little effect on equipment.

2. Shock - The MPP enclosure and deck mounting has been designed to dissipate any induced shock. In addition, the MPP shock requirements will be tested during the MPP environmental qualifications

3. Direct current (dc) magnetic field - The MPP enclosure has been designed with shielding to prevent the externally induced dc interference. The MPP dc magnetic field requirements will be tested during environmental qualifications.

Test levels for the three stresses to be measured were determined as described in the following paragraphs.

2.3.2.1 Temperature. Temperature stress is the most widely tested and is believed to be the underlying cause of the greatest percentage of electronic circuit failures. Temperature may temporarily or permanently impair the performance of the MPP unit by changing the unit's physical properties. Examples of the effects of temperature stress include variances in electronic circuit stability caused by differences in temperature gradients and differential expansion of dissimilar materials; decreases in operating lifetime caused by transformers and electromechanical components overheating; and alterations in the operating/release margins of relays and magnetic or thermally activated devices. Two subtests are provided by MIL-STD-810E: type 1 is the storage test; type 2 is the operational test. It is assumed that the operational test affects the reliability of the MPP more than the storage test, and therefore the type 1 test is not considered part of the accelerated reliability testing. The MPP specification calls for temperature testing from 10°C to 50°C with the designed temperature gradient for the MPP being from - 40°C to 70°C. MIL-STD-810E also suggests that relative humidity, if controlled, has little effect on the failure rate of electronic equipment for high-temperature testing. Airflow within the chamber should be maintained below 325 ft/min.

Extremely low temperature testing should be required only for units operating in temperatures below standard ambient. Most of the examples indicate cold operating temperatures below - 6°C. It was determined that such low-temperature testing is not consistent with the operating temperatures within a submarine.

Using the previously discussed range criteria, it was determined that the operating temperature ranges used in the accelerated reliability testing should be 10°C (low stress, high operating), 40°C (medium stress), and 70°C (high stress, maximum design).

2.3.2.2 Vibration. Vibrational stress will be induced upon the assembly under test during the ART testing. Constant vibration, normally referred to as type 1, will be induced upon the electronic assembly at one of three possible levels for each test trial. Per MIL-STD-167-1[7], this type applies to all equipment intended for shipboard use or that must be capable of withstanding the environmental vibration conditions that may be encountered aboard naval ships. MIL-STD-167-1 vibration requirements for electronics equipment were specifically developed from vibration measurements obtained from surface ships with significantly damaged drive trains (i.e., driveshaft or propeller damage). Therefore, the resulting MIL-STD-167-1 test levels are higher than the normal vibration levels on the operating submarine by orders of magnitude.

In addition, while normal vibration trials are conducted in quiet water to achieve repeatable and reliable results, actual ship operations occur in all sea states and headings with correspondingly large increases in vibration over long periods of time. Consequently, the requirements specified for ART account for the increased vibrations by being more stringent than the minimal ones usually reported. The standard provides an amplitude within the selected frequency range sufficiently large to obtain a reasonably high degree of confidence that equipment will not malfunction during service operation.

The MPP specification calls for operating within a steady state vibration frequency environment ranging from 4 Hz to 33 Hz. MIL-STD-167-1 advises a table vibratory single amplitude for an exploratory vibration test of 0.010 ± 0.002 inch. Therefore it is suggested that the vibration levels to use for the accelerated reliability testing be 0.010 ± 0.002 inch at 4 Hz (low stress), 0.020 ± 0.002 in., peak to peak, at 18 Hz (medium stress), and 0.030 ± 0.002 in. at 32 Hz (high stress).

2.3.2.3 Power. The MPP unit is powered by type 1 power. Type 1 power is 115 V, 60 Hz ungrounded and is the standard shipboard power source. An ungrounded electrical power system is a system that is intentionally not connected to the metal structure or the grounding system of the ship. This input power may vary in both voltage level and frequency, and for reliability testing constraints, it is assumed that the voltage level stresses predominate over the frequency stresses.

Per MIL-STD-1399 (NAVY) Section 300A[8], the nominal voltage for type 1 power is 115 V_{rms} with an average of the three line-to-line voltages at a tolerance of ± 5 percent, and any one line-to-line tolerance of ± 7 percent (a line voltage unbalance of 1.0 percent is allowed for submarines). The maximum departure voltage resulting from the above is ± 6 percent (108 V to 122 V), with a worst case voltage excursion from the nominal voltage of ± 20 percent (92 V to 138 V).

It was determined that the most likely high-stress voltage to affect the reliability of the MPP unit/AP drawer was the low-voltage case of 92 VAC (i.e., the voltage drops as a function of distance through a power wire from the source). High voltages are as stressful to the equipment as low voltages, though their possibility is not common as a steady state condition. It is therefore recommended that there be three accelerated reliability testing levels: 95 V (high stress), 105 V (medium stress), and 115 V (low stress).

2.3.3 Determination of the Number of Test Trials

After selection of the environmental stresses to induce onto the assembly under test X and the number of stress severity levels for each stress Y, a multi-axis parametric matrix of X^Y was developed to represent all possible combinations of stresses and levels. For the purpose of this experiment $X = 3$ and $Y = 3$ for a total of 27 possible combinations. Table 1 displays the matrix that was used during the experiment.

The individual test trials were determined by first evaluating and weighting all possible defining contrasts. It was determined that a solution can be evaluated with an acceptable degree of confidence by testing only a fraction of the total possible stress combinations. An appropriate sample set of test trials that adequately represents the contributions and interaction of the stresses was chosen by the following mathematical analysis.

Table 1. Accelerated Reliability Test-Trial Matrix

	Temperature								
	10°C			40°C			70°C		
	Voltage			Voltage			Voltage		
Vibration	115 V	105 V	95 V	115 V	105 V	95 V	115 V	105 V	95 V
4 Hz			Med		Low		Med		
18 Hz		Low		Low					High
32 Hz	Med					High		High	

For this experiment a one-third fraction of the total possible test trials was developed. The next task was to determine which particular stress combinations to test and in what order. This task was accomplished by first identifying the possible i, j, k components of the two-way interactions and the A, B, and C components of the three-way stress interactions. There exist 13 effects that could have been utilized as defining contrasts. These interactions have no physical significance, yet do prove useful in the complex designs of the overall test. Representing the three stresses are temperature, T; vibration, R; and power (voltage), V.

The following expressions represent the 13 possible defining contrasts for a three-stress test.

$$T, R, V, TR, TR^2, TV, TV^2, RV, RV^2, TRV, TR^2V, TRV^2, TR^2V^2,$$

where TR and TR^2 represent the j^{th} and i^{th} components of the TR interactions.

Next, theoretical L values that assign numerical coefficients to the test trials are calculated for each treatment by using a linear relationship

$$L = E_1X_1 + E_2X_2 + \ldots + E_iX_i, \tag{2}$$

where E_i is the exponent appearing on the i^{th} factor of the defining contrast, and X_i is the stress level of the i^{th} factor (0, 1, 2 representing low, medium, and high levels respectively) for a given test trial. Using this technique, all combinations with the same L value, modulus 3, are placed in the same matrix. For a three-level test, there are three possible L values: 0, 1, and 2. For example, if the defining contrast were TR^2V, the L value for the test trial of 012 (temperature low, vibration high, and voltage medium), is

$$L = (1 * 0) + (2 * 1) + (1 * 2) \tag{3}$$

Effects that have the same numerical L value are called aliases. Following a determination of the test trials, it is essential that the aliases be calculated and examined for reasonableness. Because the design is a one-third replicate (9 out of 27 trials), there are two aliases for each effect. Because only a fraction of the complete factorial is executed, the main effects and the interactions cannot be estimated independently. The situation arises that an estimate of a required effect also estimates one or more other effects. For this experiment, there are 12 unique test configurations that have acceptable alias patterns. Table 1 represents the test-trial matrix. The selected test trials are labeled with the respective stress levels: low, medium, and high.

1. Low - The total combined effect of the environmental stresses induced on the assembly during these test trials is believed to have a minimum effect on the performance of the assembly and has little or no impact on the life expectancy of the unit.

2. Medium - The total combined effect of the environmental stresses induced on the assembly during these test trials is believed to have an effect on the performance of the assembly and has an impact on the life expectancy of the unit.

3. High - The total combined effect of the environmental stresses induced on the assembly during these test trials is believed to have the maximum effect on the performance of the assembly and has the greatest impact on the life expectancy of the unit.

2.3.4 Determination of Unit Quantity Per Test Trial

For reliability testing, test data are a function of failures. Generally, the expected amount of test data is directly proportional to the number of units placed on test at various levels. The limiting case is the result of tradeoffs between test time and the number of assemblies tested. It should be clear that for reliability measurement, the more units tested, the less test time is required. Therefore, the following discussion establishes the minimum number of assemblies required per test trial.

The minimum number of test assemblies (sample size) required is driven by the central limit theorem. This theorem states the distribution of parameter means of a sample set approaches normality for a "well behaved" parent population distribution. Assuming the latter for the units and parameter in question, A. K. Gayen states that a minimum sample size of three to four per trial provides sufficiently distributed parameter data where the distribution sample parameter mean approximates the normal.[9]

2.3.5 Determination of Test Time

When the number of assemblies to be used at each test trial has been determined, an evaluation of the time required per trial can be made. A primary objective of this plan is to develop a test that can specifically quantify the performance relation for each test stress. If few or no failures occur during the conduct of the test, it is the responsibility of the test engineers to define an end point for the test.

To estimate the maximum times required for the individual test trials, the Weibull probability density function (PDF) is used. The Weibull PDF is a three-parameter PDF that has the ability to approximate a wide range of continuous functions. This test uses a conservative estimation of the Weibull PDF that represents an estimated life expectancy that is greater than the predicted. Since the test time is directly related to the life expectancy, longer test times result, thus producing a test procedure that approaches the conservative estimations in MIL-HDBK-781.

Inserting the conservative estimation of the Weibull PDF into the maximum likelihood function for censored data (not all units failed) allows the equation to be solved for an estimated MTBF m. It then is a simple matter to rearrange that equation to solve for test-trial time t so that

$$t = \frac{m}{-n}\ln[1 - F(t)], \tag{4}$$

where

m = initial MTBF estimation,
n = number of assemblies per test trial,
$F(t)$ = probability of witnessing a failure during testing.

The maximum time estimate for any test condition is made by considering a relatively high probability of witnessing a failure during any test trial. A 70-percent probability of failure is an acceptable estimate for complex electronic assemblies under stress. A lower probability estimate obviously reduces the test time estimate and may be warranted and implemented after review of initial testing results.

The estimated MTBF for the MPP AP drawer was derived from the mean between the Naval sheltered (NS) environment MTBF of 400 hours and the ground benign environment (GBE) MTBF of 1200 hours.

Substituting the appropriate constants m (1200), $F(t)$ (0.7), and n (3) produces a maximum test-trial time estimate

$$t = \frac{1200}{-3}\ln(1 - 0.7) = 482 \text{ hours (20 days)} \tag{5}$$

This time represents the maximum amount of test time expected to elapse before providing a single failure (neglecting any effects by stress). At worst, if no failures occur throughout the whole test, the total combined test time experienced by the test,

9 trials * 482 hours = 4338 hours (3.6 MTBF),

compares favorably with MIL-HDBK-781.

After a maximum test time for each trial has been established, the minimum test time for each test trial must be determined. The following assumptions are made during the derivation of the individual test-trial times.

1. The test consists of nine test trials which can be separated into three stress levels.

2. Time accrued at a higher stress level is at least equal to the time accrued at a lower level.

3. If an assembly has successfully completed a test without failure, it can be assumed that the assembly will complete all test trials of the same stress level or lower without failure. For example, if an assembly has passed a medium test trial, there are two other medium test trials that it is assumed to pass and three lower stress trials that it is assumed to pass. It is therefore theorized that the assembly would have passed six test trials. Because the time equation is a function of the probability function $F(t)$, and remembering that the assembly has just theoretically passed six trials, the trial time t is now multiplied by the number of trials. For six mutually exclusive trials the probability of witnessing one failure becomes

$$F(t) = (1 - e^{-6t\frac{n}{m}}). \tag{6}$$

Resolving equation (6) for trial time t results in

$$t = -\frac{m}{n * 6}\ln[1 - F(t)] \tag{7}$$

The generic form of the adjusted time equation becomes

$$t = -\frac{m}{n * p}\ln[1 - F(t)], \tag{8}$$

where p is the number of trials that could be theoretically passed.

This scaling of the calculations to adjust for the effects of increasing stress levels reduces the actual time required at the individual stress levels. It should be emphasized that testing at each trial can be terminated the instant the first legitimate failure occurs.

The remaining test times are developed by subjectively considering the relative severity of the stress combinations and dividing the test trials into three groups (H, M, and L) representing the high, medium, and low stress combinations. Each group is composed of three individual trials. Therefore, low-stress trials have an adjustment factor of 3, medium-stress trials have an adjustment of 6, and high-stress trials have an adjustment of 9. The approximate adjusted times for all levels of stress are

$$\text{Low:} \quad t = \frac{m}{-(n * 3\,\text{trials})}\ln(1-0.7) = 160 \text{ hours (6.7 days)}, \tag{9}$$

$$\text{Medium:} \quad t = \frac{m}{-(n * 6\,\text{trials})}\ln(1-0.7) = 80 \text{ hours (3.3 days), and} \tag{10}$$

$$\text{High:} \quad t = \frac{m}{-(n * 9\,\text{trials})}\ln(1-0.7) = 53 \text{ hours (2.2 days).} \tag{11}$$

Table 2 displays the AP drawer test matrix with the actual minimum test times for each of the selected trials.

Table 2. AP Drawer Accelerated Reliability Test-Trial Matrix (With Minimum Test-Trial-Times)

	Temperature								
	10°C			40°C			70°C		
	Voltage			Voltage			Voltage		
Vibration	115 V	105 V	95 V	115 V	105 V	95 V	115 V	105 V	95 V
4 Hz			80		160		80		
18 Hz		160		160					53
32 Hz	80					53		53	

The total AP expected test time is calculated as

Low stress		3 trials * 160	hours
Med. stress	+	3 trials * 80	hours
High stress	+	3 trials * 53	hours
Total test time		879	hours (36.6 days).

Applying the same time analysis detailed above to the MPP with an estimated MTBF of 250 hours and using only one unit per test trial results in the test-trial times shown in table 3.

Table 3. MPP Accelerated Reliability Test-Trial Matrix (With Minimum Test-Trial Times)

	Temperature								
	10°C			40°C			70°C		
	Voltage			Voltage			Voltage		
Vibration	115 V	105 V	95 V	115 V	105 V	95 V	115 V	105 V	95 V
4 Hz			16.7		33.4		16.7		
18 Hz		33.4		33.4					11.2
32 Hz	16.7					11.2		11.2	

The total MPP expected test time is

Low stress		3 runs * 3 trials * 33.4 hours	
Med. stress	+	3 runs * 3 trials * 16.7 hours	
High stress	+	3 runs * 3 trials * 11.2 hours	
Total test time			183.9 hours (7.7 days)

Note that because of the availability limitations of the MPP, only one unit will be available for testing. Testing one MPP unit at a time mandates that each test trial must be run three times to maintain a three-unit sample size.

Also note that since the normal life expectancy of the MPP is 10 years before refurbishment, the total expected test time accrued for the AP drawers and MPP unit combined is less than 2 percent of its total life.

2.3.6 Total Quantity of Assemblies Needed

The final consideration was to determine the total number of assemblies needed for testing. The repairability of the test assembly as well as the effectiveness of repairs play a significant role in determining the total number of assemblies required for test. It was determined that failed units will be repaired by the replacement of failed cards or components, but the entire assembly will not be refurbished before the next test trial. Repairing and maintaining the units greatly reduces the total number of assemblies needed for completion of the entire accelerated reliability test.

For a test consisting of 9 total trials with 3 units per trial, a maximum of 27 assemblies would be needed if all assemblies failed at each individual trial and were not repaired. For test trials performed sequentially, only three assemblies are necessary for each trial (see paragraph 2.3.4), given sufficient repair capabilities. This is feasible with the AP assemblies, but given the limited number of MPPs available, only one MPP is cycled through each trial duration. The subsequent MPP test-trial time calculations reflect this consideration. For the purpose of this test, it was also concluded that units would be inspected by the test engineers to determine the effects of cumulative test time, effectiveness of repair and maintenance activities, and overall retestability of the units.

Total test time can be reduced by placing more units at each test trial. Examination of equation (4) reveals that test-trial time t is a function of the probability of witnessing a failure during the test $F(t)$, and the number of units placed at that test trial n. Placing three MPPs on trial simultaneously as opposed to sequentially testing one unit reduces the total test time by 67 percent. Although this method increases the number of MPPs and simulators required, it still reduces the overall personnel and facility expenditures. A detailed breakout of test expenditures is given in section 4.6.

2.3.7 Stress Analysis

2.3.7.1 Stress Analysis (Theoretical Discussion). The experimental design proposed for this effort is a one-third replicate of a 3-factorial having three test stresses each at three levels. It is assumed that the effects of accumulated test time and the effectiveness of repair and maintenance activities will require the use of multiple test units. The following discussion assumes the stress factors, test methodology, and parameters previously described.

The general equation for calculating the mean based on the three stress factors chosen is given as

$$\hat{Y}_{ijk} = \mu + A_i + B_j + AB_{ij} + C_k + AC_{ik} + BC_{jk} + ABC_{ijk} + \varepsilon_{ijk}, \qquad (12)$$

where

$\dot{Y}_{ijk}$ = the calculated mean MTBF,
μ = the grand mean (i.e., mean of all experiments),
A_i, B_j, C_k = sum of the main effects,
$AB_{ij}, AC_{ik}, BC_{jk}, ABC_{ijk}$ = sum of the interactive effects,
ε_{ijk} = independent random variable with a zero mean and a fixed variance.

Through the DOE, the test trials may be designed to produce multiple test data that can be used to define the contributions of the stress factors to the MTBF equation. The resulting equation, with its associated calculated stress coefficients, can be used to predict the MTBF at stress conditions where empirical data were not necessarily gathered

To solve for the coefficients of the stress terms, both main effects and interactive effects, the DOE must be analyzed to ensure that the multiple test trials will produce definitive data. The calculation of the stress coefficients consists of analyzing the data gathered in the test trials and curve fitting the results (i.e., defining a mathematical expression that approximates the curve of the gathered data). Curve fitting of the data to an equation and model consists of minimizing the difference between the model value prediction and the actual results of the testing. Traditionally curve fitting is accomplished using the "normal equations."[10]

Normal equations are defined as follows and consist of p+1 equations and p+1 unknowns:

$$\sum_{i=1}^{n} y_i = nb_0 + b_1\sum_{i=1}^{n} x_i + \ldots + b_p\sum_{i=1}^{n} x_i^p, \tag{13}$$

$$\sum_{i=1}^{n} x_i y_i = b_0\sum_{i=1}^{n} x_i + b_1\sum_{i=1}^{n} x_i^2 + \ldots + b_p\sum_{i=1}^{n} x_i^{p+1}, \tag{14}$$

$$\downarrow$$

$$\sum_{i=1}^{n} x_i^p y_i = b_0\sum_{i=1}^{n} x_i^p + b_1\sum_{i=1}^{n} x_i^{p+1} + \ldots + b_p\sum_{i=1}^{n} x_i^{2p}. \tag{15}$$

The higher the order of the equations (i.e., the more terms in the polynomial), the better the curve fit, the better the definition of the stress coefficients, and the lower the error between the calculated and the actual test values. Traditionally the analysis of the order of equations is limited to the last polynomial expression that adds to a significant modification of the least squares value. Many techniques are available for solving the equations. Orthogonal polynomials are among the simplest curve-fitting techniques, if the x-values chosen in the trial are equally spread. The advantages of this method are that as the degree of the polynomial increases, additional terms can be added simply and easily. These terms are independent of those already considered. Therefore, the development of the polynomials reduces to a simple matter of adding the linear terms. Once each of the stress terms has been developed, simply adding all the terms to a single mean value renders the overall stress model.

After the equation for the MTBF has been calculated, MTBF predictions may be deduced by substituting the stress values for the coefficients. It should be stated that by the DOE and by selection of the test configurations and parameters, the calculated MTBF is valid for only a specific range of stresses. During the calculation of coefficients, the analyst may have to determine which terms are significant by using ANOVA analysis. The ANOVA technique analyzes each of the effects, both main and interactive, to determine their significance. The technique is well documented and determines the F distribution ratio (the ratio of the effects' mean squared to the error mean squared) from the effects' degrees of freedom (one less than the test levels), the sum of the squares of the predicted MTBF calculation, and the actual mean squared (the ratio of each effects sum of squares and degrees of freedom). The calculated F distribution is compared to the table lookup F-distribution value based on degrees of freedom and level of significance. Based on this comparison, the analyst may determine the significance of the level of the polynomial expression, the significance of the interaction of the stresses, or the significance of the stress coefficients.

*2.3.7.2 **Stress Analysis (Example).*** The application of the MTBF and stress relationship equations, described in paragraph 2.3.7.1, has been exercised in various experiments and in the validation and verification of accelerated reliability documentation. The following example is presented as clarification of the mathematical discussion in paragraph 2.3.7.1.

The data were extracted from a Rome Laboratory test procedure example. The example chose a unit for which the MTBF was to be calculated using the accelerated reliability techniques described previously. It was speculated in the example that temperature, vibration, and voltage were the most detrimental factors affecting the unit reliability. The following assumptions were made:

1. The MTBF was estimated at 2000 hours using MIL-HDBK-217.
2. The temperature test levels were determined to be at 40°C, 70°C, and 100°C.
3. The vibration levels were established as 3 g_{rms}, 5 g_{rms}, and 7 g_{rms}.
4. The voltage test levels were established as 0.5 eV, 1.0 eV, and 1.5 eV.
5. The unit failure distribution was determined to be normal.
6. The number of units per test trial was three.

The test times for the low-, medium-, and high-stress conditions were calculated as

time (low stress) = $\ln(0.3) * (2000) / -(3 * 3) = 267$ hours,
time (medium stress) = $\ln(0.3) * (2000) / -(3 * 6) = 134$ hours, and
time (high stress) = $\ln(0.3) * (2000) / -(3 * 9) = 89$ hours.

A one-third fractional factorial replicate was chosen and the reliability tests were run. Table 4 illustrates the actual test results (parenthesized results indicate no failure during the test; a calculated value was substituted).

Table 4. Example Test Results Matrix

	Temperature								
	40°C			70°C			100°C		
	Voltage			Voltage			Voltage		
Vibration	0.5 eV	1.0 eV	1.5 eV	0.5 eV	1.0 eV	1.5 eV	0.5 eV	1.0 eV	1.5 eV
3 g_{rms}			240		720		360		
5 g_{rms}		(1151)		(1151)					33
7 g_{rms}	(575)					81		121	

The natural logarithms of the values were calculated and summed. The data were then subjected to the ANOVA F-tests with the results shown in table 5.

Table 5. ANOVA F-Test Matrix

Effect	Degrees of Freedom	Sum of Squares	Mean Squared	F
Temperature linear term	1	3.688	3.688	40.9
Temperature quadratic term	1	0.494	0.494	5.5
Voltage linear term	1	5.837	5.837	54.8
Voltage quadratic term	1	0.974	0.974	10.8
Vibration linear term	1	0.961	0.961	10.6
Vibration quadratic term	1	0.159	0.159	1.76
Error	2	0.180	0.09	
Total	8	12.293		

This analysis indicates significant factor effects for all three stresses. Further, the quadratic effects of temperature and voltage are also significant. Therefore, the terms modeled were the linear effects of all three stresses and the quadratic effects of temperature and voltage. The terms for the polynomials were then calculated as

$$\ln(\hat{Y}) = \beta_0 + T_L\varepsilon_1' + T_Q\varepsilon_2' + V_L\varepsilon_1' + V_Q\varepsilon_2' + R_L\varepsilon_1', \tag{16}$$

where

$\hat{Y}$ = an estimate of MTBF,
β_0 = grand mean = 5.676,
T_L = linear effect of temperature = -0.784,
T_Q = quadratic effect of temperature = -0.165,
V_L = linear effect of voltage = -0.986,
V_Q = quadratic effect of voltage = -0.232,
R_L = linear effect of vibration = -0.400,
ε_1 = linear term for polynomial = stress,
ε_2 = quadratic term for polynomial = 3 * (stress^2 - 2/3) = 3 * stress^2 - 2.

Combining these terms yields

$$\begin{aligned}\ln(\text{MTBF}) = {} & 5.676 - 0.784\text{temp} - 0.165*(3\text{temp}^2 - 2)\\ & -0.986\text{volt} - 0.232*(3\text{volt}^2 - 2) - 0.4\text{vibr}.\end{aligned} \tag{17}$$

Table 6 displays the results of applying the stresses to the above equations and compares them to the actual/(predicted) test results (bolded figures are calculated from equation (17)).

Table 6. Example Test Results Comparison Matrix

	Temperature								
	40°C			70°C			100°C		
	Voltage			Voltage			Voltage		
Vibration	0.5 eV	1.0 eV	1.5 eV	0.5 eV	1.0 eV	1.5 eV	0.5 eV	1.0 eV	1.5 eV
3 g_{rms}			240 239		720 966		360 358		
5 g_{rms}		(1151) 862		(1151) 863					33 33
7 g_{rms}	(575) 771					81 81		121 120	

The example presented exercises the mathematics described in paragraph 2.3.7.1. The values of the calculated and actual test results compare favorably, except for the fifth test, medium temperature and voltage, and low vibration. An analysis of the equation shows that the vibration term has the highest impact on the stress equation. The validity or invalidity of this point requires further analysis, however.

Although the results of the mathematics used in the example are definitive, their application to the problem figures must be properly analyzed. All factors involved in setting up and running the test must be carefully considered in any interpretation of the results. For example, in the specific problem presented (the calculation of the MTBF of the MPP unit and its AP drawers), reliability engineering must be applied to draw the proper conclusions from the mathematics presented.

3. TEST CONDUCT

Section 2 defined a methodology for accelerated reliability testing of the MPP and its AP drawers. This section discusses the proposed implementation of the methodology.

3.1 PERFORMANCE MONITORING

During ART the MPP and the AP drawers must be operational in an environmental chamber that can induce the three previously defined environmental stresses—temperature, vibration, and power. A fault or failure occurs when any internal component/lowest replacable unit (LRU) does not perform a function that is observable on the test equipment or display monitors. Mission profiles are dynamic and are not considered part of the test criteria.

Equipment failure can be detected in two ways. The MPP unit performance monitoring (PM) function tests the functionality of unit individual assemblies every 7 minutes and reports any failures. The system specification for the PM function dictates that it find 94.7 percent of possible failures, with a false-alarm failure rate of less than 2 percent (implying that the PM function may not find all failures during testing). To ensure operational detection of failures, therefore, the MPP unit should be baseline operating test (BOT) tested before and after reliability testing to ensure the PM has not misrepresented any failures. The second method of detecting failures is to stimulate the drawer and observe the various outputs produced by that drawer via test and simulation equipment. This observation can be automated to reduce the amount of human intervention required. The decision whether to use automated failure detection will be made when the detailed test procedures are written.

3.2 CONFIGURATION

It is assumed that electronic units must be operating to produce the failures that the MTBF reliability testing will detect. Units that operate in the standby mode exhibit different operational and failure characteristics than units that are fully operational. This assumption is based on differences in current draw between units in the two operational states. This premise may be proven empirically by testing the current consumption of the AP drawers under different operating conditions. It is recommended that the AP drawers be configured identically and be in a fully operational state for reliability testing.

Figures 2 and 3 depict the reliability testing configuration for the MPP unit and AP assemblies, respectively. The resulting data provide reliability figures for the MPP on a system level, and for the AP drawers directly. The SC drawer MTBF can be implied from the AP drawer data. Reliability data for the miscellaneous equipment, fans, backplanes, etc. are known. TAD reliability can be calculated by subtracting the reliability figures for the AP drawers, miscellaneous equipment, and SC drawer from the MPP reliability data. As a result, all subequipment delineated in the MPP specification can be tested/calculated.

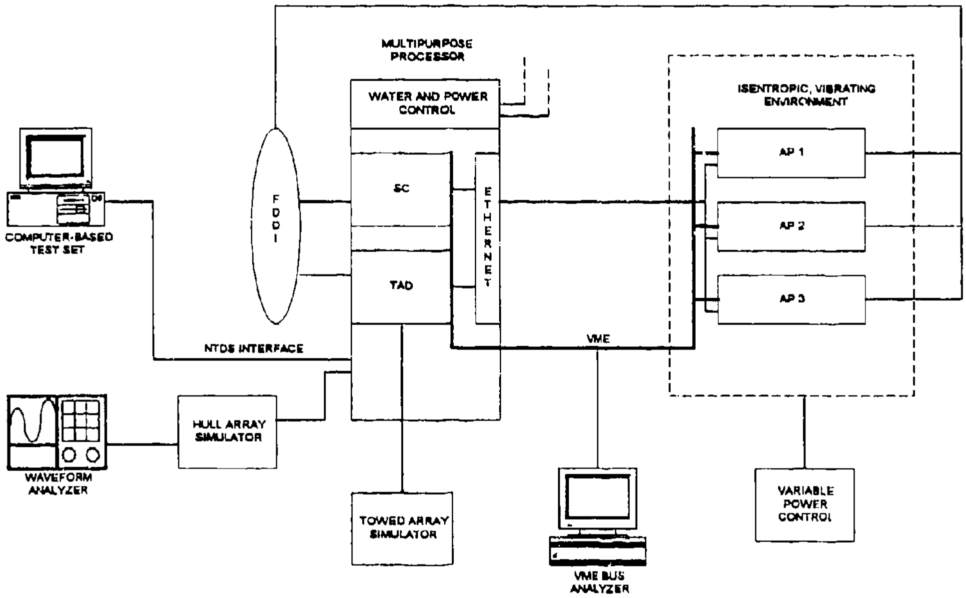

Figure 2. AP Accelerated Reliability Testing Configuration

When testing the MPP, the entire unit will be on/in an environmental chamber and only the test equipment will be located off the test platform. When testing the AP drawers alone, the entire MPP will be operational; however, those hardware elements of the MPP that do not require environmental test will be separated from the chamber, where possible. (It is anticipated that the SC drawer and the TAD, with their associated equipment, will not be in the environmental chamber for AP drawer testing). In either of the two tests the MPP unit will receive its initial program load (IPL) and its configuration by the workstation software through the Naval Tactical Data System (NTDS) channel.

The MPP unit and the AP drawers may be configured in multiple possible configurations. It has been determined that the standby configuration is a minimally stressful configuration for reliability testing. The configuration that stresses all three AP drawers and exercises all of the functions and cards within the drawers is the TB29 spatial vernier configuration. This configuration conducts TB16/29 spatial vernier processing in two of the drawers, and does TB16/29 conventional and hull array processing in the third. Though the drawers will have different processing loads, it is assumed that the stressful load is divided fairly evenly among them from a reliability point of view. This premise may be proved by measuring and comparing the current draw for the individual drawers.

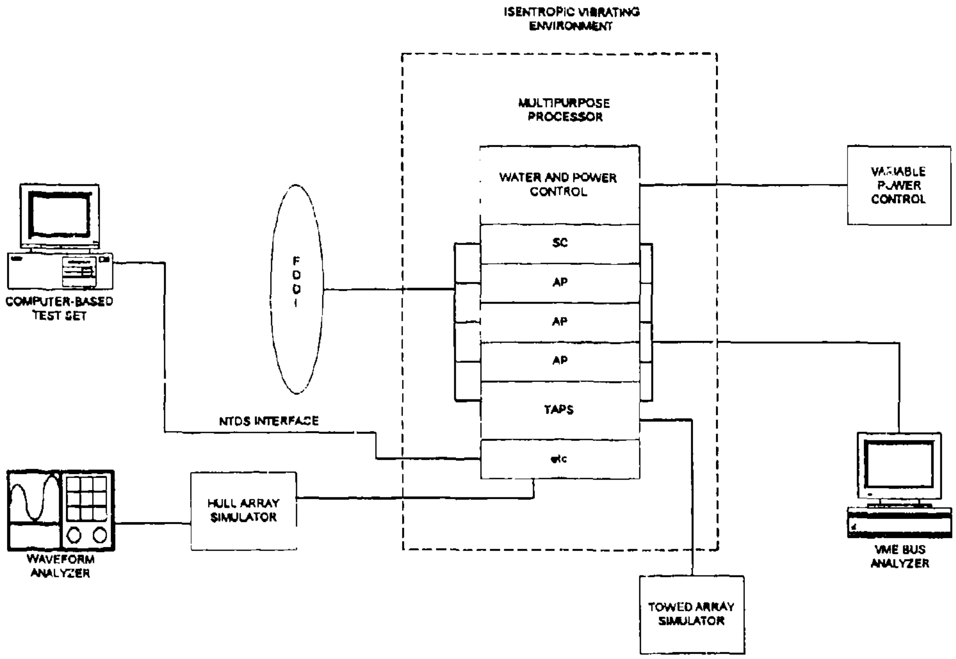

Figure 3. MPP Accelerated Reliability Testing Configuration

Once configured and rendered operational, the MPP/AP drawer(s) must be simulated with the proper signals. These signals are generated by the SC drawer and the TAD within the MPP unit and the various external simulators. These simulators will be defined in detail when the test procedure is written. Further study is necessary to determine the exact combination of test equipment and simulators required to exercise all of the MPP/AP drawer functions.

3.3 SETUP

To preserve test integrity, only one type of test will be run at any particular time (i.e., either the MPP or the AP drawer reliability test). An MPP test that fails as the result of an AP drawer failure may be used as a data point for both tests, if the same factorial tests and stress levels are chosen in the two testing configurations. Using the AP drawer failure data would reduce test time without jeopardizing data integrity; a fortunate happenstance, not necessarily an expected result. A test trial will be stopped if there is a nonprime equipment failure during testing. The nonprime item will be repaired and the test trial evaluated to determine if it should be continued or canceled and repeated. This evaluation will be done in accordance with the criteria defined in the test procedure.

The testing configuration will consist of the MPP unit connected to the workstation; the simulators, stimulators, and associated test equipment; the water cooling; and the type 1 power. Only the MPP unit will be connected to the environmental chamber. When the AP drawers are being tested, the three drawers will be in the environmental chamber on a vibration table within the MPP cabinet. The remaining equipment not requiring environmental testing will not be connected to the environmental chamber.

The operation of the MPP unit and/or AP drawers will be observed on the various test equipment, such as the versa module eurocard (VME) bus analyzer, the waveform analyzer, and the workstation software. The workstation software has the capability to emulate the tactical equipment displays. Therefore, as the output of the AP drawers is transferred to the workstation via the FDDI and Ethernet interfaces, the tactical displays can be observed to ensure the proper operation of the MPP unit and/or the drawers. Automated software may be substituted for this human observation where possible.

3.4 REPAIR

The LORAL facilities in Manassas, Virginia will provide MPP module repairs generated by ART. It is proposed that LORAL and Digital Systems Research be used to perform the fault analysis on those subassemblies rejected by testing, repair the faulty electronics, and return the device. A spares complement would be beneficial in minimizing environmental testing downtime while waiting for module repair. The repair facilities will be asked to record all failure and repair data. These data will be correlated and reviewed at the completion of testing for failure-mechanism determination.

Prior to starting a new test trial, the test investigator will determine whether there is evidence of accumulated stress wear on the AUT. Evidence of stress wear will prohibit use of the AUT in successive tests. However, given the 10-year operational life of the MPP, it is not anticipated that the hours required for testing will significantly impact operability.

3.5 REPORT

The data recorded during ART will be presented in a final report that will include the following items:

- orthogonal polynomial calculations used to resolve the stress effect parameters,
- ANOVA analysis that illustrates the level of significance that each stress contributes to the overall failure rate,

- resultant MTBF stress model with sample applications to current stress environments,
- review of the returned repair data and identification of critical stresses and critical failure items, and
- performance data and user feedback recorded during the test period for analysis by the MPP community.

4. TEST RESOURCES

4.1 TEST FACILITIES

The NUWC Division Newport facility possesses the resources (space, equipment, and testing personnel) required to perform ART on the MPP. Testing at NUWC Division Newport would require NAVSEA to provide the MPP subassemblies, proposed MPP enclosures, and a spares complement to the facility.

4.2 TEST ASSEMBLIES

Section 3.2 details the testing configuration for the accelerated reliability testing of the individual AP drawers and MPP unit. It is anticipated that an MPP unit will be made available for testing, along with its associated simulators and test equipment. In addition, a spares complement to replace failed LRUs during testing is requested. The actual repair of the failed LRUs will be accomplished at the repair facility, but spare LRUs should be made available with the MPP unit to minimize downtime during testing.

4.3 TEST EQUIPMENT

Existing test equipment available from the NUWC activities and the prime contractor will be utilized. High-precision, real-time signal recorders and data acquisition systems will be used during testing. Equipment not located at the test facility will be requisitioned as needed and dispensed to the test site.

Any small-scale expenditures needed for developing test software, hardware fixtures, interfaces, or other capital assets can be leveraged across several acoustic programs requiring similar testing.

During the ART period several test stresses will be combined and tested at once. Therefore, all stress-inducing test equipment must be located at the facility at the beginning of each test.

4.3.1 Environmental Stress Equipment

The reliability test will be conducted in a thermal chamber mounted on a vibration table with controlled power supplying the AUT. Required environmental equipment includes the thermal chamber, vibration table, and power supplies.

4.3.1.1 Thermal Chamber. The thermal chamber will be capable of the controlled steady-state temperature delineated by the accelerated reliability temperature requirements. It is understood that instead of mounting the actual temperature chamber on the vibration table, a customized thermal chamber enclosure may be required. However, the temperature accuracy of the custom chamber must be within the accuracy of the test chamber external to the AP drawers and MPP unit testing environment.

4.3.1.2 ***Vibration Table.*** The vibration table will be capable of supporting the thermal chamber and the entire MPP unit. The unit will be mounted directly to the table without the use of noise isolation mounts. The operating characteristic requirements of the table are defined in paragraph 2.3.2.2.

4.3.1.3 ***Power Supplies.*** Paragraph 2.3.2.3 describes the Navy type 1 power requirements necessary for testing the MPP drawers. Figure 4 depicts the test control and recording equipment configuration required to achieve the necessary control of the power supply and induce the proper environmental stress.

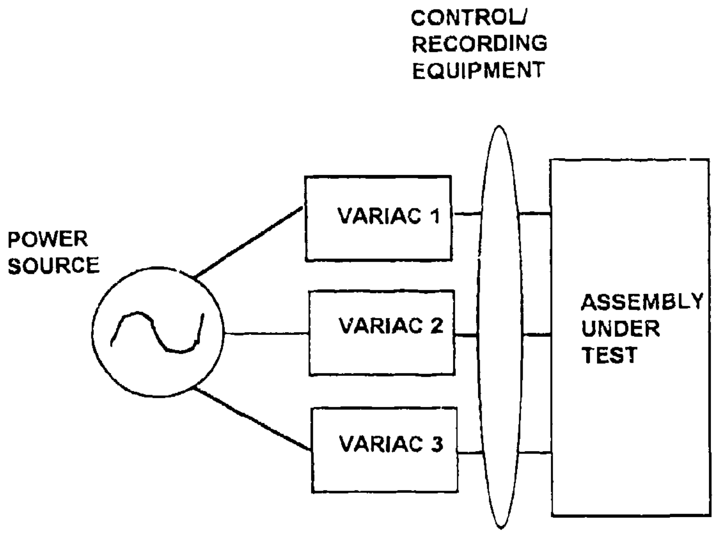

Figure 4. Reliability Test Controlled Power Configuration

4.3.2 Functional Measurement Equipment

As shown in section 3.2, the test equipment required falls into two categories: test equipment required to observe the proper operation of the units under test, and test equipment to monitor the environmental stresses imposed on the AUT. A detailed list of the equipment will be provided upon release of the detailed test procedure. A cursory list includes a UNIX workstation; a waveform analyzer; a VME bus analyzer; and equipment to measure and record vibration, temperature, and power.

The computerized data recording equipment used for the ART must have the ability to record the following signals with a precision not less than the precision of the signal source or that of the intermediate measurement device:

- temperature
- vibration
- voltage.

Data acquisition software is required to receive and record signals from measurement sources and to compare the input and output signals graphically. LABVIEW is one example of software that could be used for data acquisition, storage, and comparison, and for display of signals acquired from the electronic measurement equipment.

4.4 TEST DOCUMENTATION

The test facilities must be equipped with the full set of manufacturer's specifications for each item under test; a full set of user manuals for each piece of test equipment; and the preliminary stress profiles, modeling information, and expected fault analysis information for each cell to be tested.

4.5 TEST PERSONNEL

A combined minimum of three test representatives will be required for testing. The test team will be composed of representatives from government, test facilities, and contractor organizations. These organizations will be required to provide representation for the entire duration of the testing (approximately 50 days for the MPP and AP testing).

4.6 TEST EXPENDITURES

Table 7 provides a summary of the resources required to conduct the proposed ART and compares them with the resources required by the traditional RDT (TAAF/FRACAS) process.

Table 7. Total Resources Required Comparison Matrix

Resource	ART	RDT (TAAF/FRACAS) PROCESS
Test Duration:		(Note 1)
• MPP	250 hours	1050 hours
• AP	1000 hours	4500 hours
• SC	(Note 2)	6800 hours
• TAD	(Note 2)	13600 hours
• Facilities	1000-1250 hours	4500 hours
Test Units/Spares		
• Total MPPs	1 unit, 3 AP drawers	2+ units
• Spare LRUs	20 modules	Multiple (Note 3)
Test Personnel		
• Equipment	120 work-hours	450 work-hours
• Facility	1250 work-hours	4500 work-hours
• Reliability Test	120 work-hours	2250 work-hours
• Failure Analysis	120 work-hours	450 work-hours
Total	1600 work-hours	7600 work-hours

NOTES:

1. Best-case estimates were taken for traditional RDT comparisons.
2. Reliability data from AP and MPP testing will be evaluated based on the relative complexity of the SC drawer and the TAD.
3. LRUs will be replaced on an as-fail basis and failed modules will be sent to a repair facility.

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APPENDIX
MATHEMATICAL ASSISTANCE

The development of the ART requires that a myriad of tasks be completed successfully before the MTBF model can be calculated. These tasks are not trivial in nature and require the use of many disciplines, including test planning, design of experiments, stress analysis, test trial definition, test trial implementation, and data gathering and analysis. During the lifecycle of the ART plan and the execution of these tasks, many "what if" questions arise that require the exercise and re-exercise of the mathematics described in this document.

To assist readers in the understanding and exercise of the mathematics presented, the author has provided an electronic spreadsheet, written on an IBM PC-compatible 1.44 megabyte floppy diskette in Microsoft EXCEL, version 5.0 format, in the back pocket of this document. The spreadsheet includes a cursory explanation of the mathematics it contains, but it should be used in conjunction with the descriptions contained in this document for a complete understanding.

The example contained in the spreadsheet and depicted in the following pages is the same example presented in detail in paragraph 2.3.7.2.

Accelerated Reliability Test Spreadsheet - Introduction

The enclosed workbook was written to be used in conjunction with the "Multipurpose Processor Accelerated Reliability Test Plan," authored by M. Nehra, NUWC Division Newport, Code 433. A detailed description of the algorithms used and the derivation of the equations are also contained in "Accelerated Reliability Testing Utilizing Design of Experiments," Barry T. McKinney, ROME Laboratory, Griffiss Air Force Base, New York.

The following mean time between failure (MTBF) calculation is based on the mathematics presented in the reference es and the example(s) presented in the test plan document. The calculated values, displayed in yellow on the computer screen, are based on inputs, displayed in green.

Min/Max Stress Ranges:

	Low Stress		High Stress	(units)
Temperature = from	40	to	100	C
Voltage = from	0.5	to	1.5	[illegible]V
Vibration = from	3	to	7	Grms

Enter Environmental Values to Calculate MTBF:

		Normalized
Temperatur	40	-1.00
Voltage	0.5	-1.00
Vibration	3	-1.00

MTBF = **1716.99**

Legend:

(shaded)	Operator Entry
	Calculated Result(s)
	Intermediate Result(s)

This workbook uses the following steps, and associated spreadsheets, to calculate the MTBF model:

1) Determine maximum test times	Sheet(s): Test Times
2) Enter resultant test times	Sheet(s): Test Times
3) Intermediate calculations	Sheet(s): Calculations
4) Perform the analysis of variance	Sheet(s): ANOVA
5) Calculate the model coefficients	Sheet(s): ANOVA
6) Calculate the MTBF	Sheet(s): Introduction, Test Times

Accelerated Reliability Test Spreadsheet - Test Times

First, a maximum test time is calculated for low-, medium-, and high-stress environments. The maximum test time is then multiplied by the number of units under test. If none of the units under test fail before the maximum test time, an assumed chi squared distribution value is entered into the test matrix.

Maximum Test Time Calculation (in estimated MTBF units)

		low stress test time =	267.55	for	**802.65**	if no	**1157.98**	chi**2 MTBF
Est MTBF =	2,000	med stress test time =	133.77	3	**401.32**	failure	**578.99**	@Prob %
prob % =	70	high stress test time =	89.18	units	**267.55**	enter:	**385.99**	60

After the test times have been bounded (see above) and the one-third fractional factorial replicate has been chosen, the test times may be entered into the proper matrix elements.

Resultant Test Time Matrix (in estimated MTBF units)

	Low Temp			Medium Temp			High Temp		
	Low Volt	Med Volt	High Volt	Low Volt	Med Volt	High Volt	Low Volt	Med Volt	High Volt
Low Vib			240		720		360		
Med Vib		1151		1151					33
High Vib	576					81		121	

After the test time values have been entered into the resultant test-time matrix, the spreadsheet calculates the MTBF Model (see remaining sheets). For readability, and convenience, the values of low, medium, and high stresses are applied to the MTBF model presented on the ANOVA sheet, and the resulting calculated MTBF matrix is presented:

Resultant Calculated MTBF Matrix (in estimated MTBF units)

	Low Temp			Medium Temp			Hig Temp		
	Low Volt	Med Volt	High Volt	Low Volt	Med Volt	High Volt	Low Volt	Med Volt	High Volt
Low Vib	**1716.99**	**1286.72**	**238.87**	**1288.49**	**965.60**	**179.25**	**357.81**	**268.14**	**49.78**
Med Vib	**1150.67**	**862.32**	**160.08**	**863.50**	**647.11**	**120.13**	**239.79**	**179.70**	**33.36**
High Vib	**771.14**	**577.89**	**107.28**	**578.69**	**433.67**	**80.51**	**160.70**	**120.43**	**22.36**

Accelerated Reliability Test Spreadsheet - Calculations

Following the entry of the test times into the test-time matrix, the natural log of the values is calculated.

Natural Log of Test Time Matrix

	Low Temp			MediumTemp			High Temp		
	Low Volt	Med Volt	High Volt	Low Volt	Med Volt	High Volt	Low Volt	Med Volt	High Volt
Low Vib	0.0000	0.0000	5.4806	0.0000	6.5793	0.0000	5.8861	0.0000	0.0000
Med Vib	0.0000	7.0484	0.0000	7.0484	0.0000	0.0000	0.0000	0.0000	3.4965
High Vib	6.3544	0.0000	0.0000	0.0000	0.0000	4.3944	0.0000	4.7958	0.0000

The natural l ogs of the test times are then summed by stress values.

Summation of Stresses Matrix

	Low	Medium	High
Temperature	18.8834	18.0221	14.1784
Voltage	19.2889	18.4234	13.3716
Vibration	17.9460	17.5933	15.5446

Finally, a contrasts matrix is created based on the orthognal nature of the stress ses to determine the contribution of each stress.

Contrasts Matrix

	Low Coef	Med Coef	High Coef	Temp Cont	Volt Cont	Vib Cont
Linear	-1	0	1	-4.7050	-5.9173	-2.4014
Quad	1	-2	1	-2.9824	-4.1864	-1.6960

Accelerated Reliability Test Spreadsheet - ANOVA

After the intermediate calculations have been completed, an analysis of variance is performed on the data to determine the significant contributions of the linear and quadratic elements of the stress terms to the MTBF model. By comparing the calculated F-ratio to a look-up table value, the operator may determine the significance of the stress(es) and may choose to incorporate the term(s) into the MTBF model by ente ring a 1 o 0 (1 = significant, 0 = not significant), respectively.

Analysis of Variance Table

	Polynomial	Sum of Sq	Deg of Free	Mean Squ	F Ratio	Significant? (1=Yes; 0=No)
Lin Temp	2	3.6895	1	3.6895	41.2915	[illegible]
Quad Temp	6	0.4941	1	0.4941	5.5303	[illegible]
Lin Volt	2	5.8357	1	5.8357	65.3107	[illegible]
Quad Volt	6	0.9737	1	0.9737	10.8969	[illegible]
Lin Vib	2	0.9611	1	0.9611	10.7564	[illegible]
Quad Vib	6	0.1598	1	0.1598	1.7883	[illegible]
Error		0.1787	2	0.0894		
Total		12.2926	8			

Once the Analysis of Variance is completed, the MTBF model coefficients are calculated and used in the MTBF model as follows:

ln(MTBF)=GM+LT*temp+QT*(3*temp2-2)**
+LVt*volt+QVt*(3*volt2-2)**
+LVb*vib+QVb*(3*vib2-2)**

Model Coefficients	Coefficients
Linear Temp (LT)	**-0.7842**
Quadratic Temp (QT)	**-0.1657**
Linear Volt (LVt)	**-0.9862**
Quadratic Volt (QVt)	**-0.2326**
Linear Vib (LVb)	**-0.4002**
Quadratic Vib (QVb)	**0.0000**
Grand Mean (GM)	**5.6760**

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